# Why is snow important in the southwestern United States?

## Investigation Overview

In Investigation 4, students role-play U.S. senators from seven western states seeking to find solutions to important water problems in the Southwest: recurrent drought, which reduces vital snowpack resources, in the face of rapid population growth and therefore increasing demand on those resources. Information from satellite images, in tandem with ground-based perspectives, assist students in playing their roles as senators. Because the investigation uses a case study in the United States, all statistics will be in English units. This conscious exception to the standard use of metric units reflects the real-world practice of American water resource managers.

Time required: Five to nine 45-minute sessions (as follows):
- Introduction and Parts 1 and 2: One or two 45-minute sessions
- Part 3: One 45-minute session
- Parts 4 and 5: One or two 45-minute sessions
- Parts 6 and 7: One or two 45-minute sessions
- Part 8 and Debriefing: One or two 45-minute sessions

## Materials/Resources

Briefing (one per student)
Log (one per student)
Computer with CD-ROM drive. The Mission Geography CD contains color graphics that contain data needed for the investigation.
Access to an atlas with an index to show location of cities in the western United States
Optional: Access to the Internet, which offers opportunities for extending this investigation

## Content Preview

The southwestern United States faces critical water shortages. The Southwest is the driest quarter of the United States and yet its population is growing faster than that of any other region. Most of the population depends upon mountain snowmelt for its water supply, but the amount of snow varies, and the climate is subject to recurrent droughts. The allocation of water among both competing uses and areas is a huge political and management problem.

## Geography Standards

### *Standard 7: Physical Systems*
***The physical processes that shape the patterns of Earth's surface***
- Describe how physical processes affect different regions of the United States and the world.

### *Standard 15: Environment and Society*
***How physical systems affect human systems***
- Analyze examples of changes in the physical environment that have reduced the capacity of the environment to support human activity.
- Apply the concept of "limits to growth" to suggest ways to adapt to or overcome the limits imposed on human systems by physical systems.

### *Standard 18: The Uses of Geography*
***How to apply geography to interpret the present and plan for the future***
- Develop policies that are designed to guide the use and management of Earth's resources and that reflect multiple points of view.
- Analyze a variety of contemporary issues in terms of Earth's physical and human systems.

### *Geography Skills*
***Skill Set 4: Analyzing Geographic Information***
- Make inferences and draw conclusions from maps and other geographic representations.

***Skill Set 5: Answering Geographic Questions***
- Evaluate the answers to geographic questions.

## Classroom Procedures

### *Beginning the Investigation*

1. Tell students that in this investigation they will play the roles of senators from seven western states on the Senate Subcommittee on Future Water Policy in the Southwest. Generate initial discussion by asking questions such as:
   - Why might there be a need for changing water policies in this region?
   - What kinds of issues might you expect to face in doing this?

2. Organize for cooperative learning by forming students into seven small groups:
   - Form a small group for Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.
   - Give students some choice of group, randomly assign, or count off by seven.
   - All groups do not need to be the same size: assign larger groups to the more populous states (California is by far the largest, followed by Arizona and Colorado; Wyoming has the smallest population).
   - Students help each other in their small group learn to play the role of their state's senator.

   (Cooperative learning will be completed in Part 8 when students from each group come together in groups of seven to formulate recommendations.)

3. Hand out copies of the **Briefing** and **Log** to each student. (Alternative: If you don't want each student to complete a Log, hand out only one copy per group.)

4. Have students look over the **Briefing** and **Log** and emphasize
   - the importance of studying the images (called figures) that support the written material;
   - the questions and the need to write out answers on the Log (answers are provided at the end of this Educator's Guide); and
   - the schedule for handing in answers on the Log, either all together at the conclusion, or one or two at a time as they complete individual parts of the investigation.

5. In their small groups,
   - have students read **Background**, **Objectives**, and **Scenario**;
   - take any questions they may have; and
   - tell them they should begin working through the Briefing in their small groups—reading, studying the figures, discussing, and answering the Log questions.

6. For students who do not live in the Southwest, ask: Why would you care about this region's water problems? Student responses might include
   - the Southwest provides fresh fruits and vegetables to the rest of the country;
   - the economic burdens caused by regional problems, such as drought or flooding, are often borne by the rest of the country through federal assistance; or
   - you should care about the problems of people in other places.

### *Developing the Investigation*

7. Beginning with **Part 1: Why is this investigation important?**, small groups can work through the material on their own.
   - If you want to keep the groups progressing at about the same pace, you might conduct whole class discussions on interesting and difficult points and/or of the Log questions.
   - From Part 1, for example, you might check for understanding of the concept of reservoir storage and hydropower by asking: "How is snow used to make electricity?" and "What is meant by the phrase water-stressed areas?"
   - The first **Log** question comes at the end of Part 2**.** Remind students that in answering the Log questions carefully, they are preparing to play their roles as members of the Senate Subcommittee on Future Water Policy in the Southwest.

8. At the beginning of **Part 3: How much do cities in the Southwest depend on snow?**, Question 2 directs students to complete the table in the **Log**. The table is designed to help students organize the information in Part 3 as they cover it.
   - Students should find all the locations referred to, either on Figure 4 or in an atlas.
   - Ask students to match features on the images (figures) with features in their atlases. For example, they should try to find Lake Powell in the atlas (or on Figure 4) and compare the map view with the image in Figure 2.
   - Another check could occur with Figure 5. Have them find the Sierra Nevada Mountains, California Central Valley, and San Francisco Bay area on a map. Then, have them identify these features on the oblique NASA image in Figure 5.
   - Have students orient their atlases to try to reproduce the angles of the oblique photos in Figures 5, 7, and 9. Be sure directions also correspond.

9. Encourage brainstorming to answer Question 3 at the end of Part 4.

10. **Part 5. Who's in charge of the water?** discusses the importance of the Colorado River to the region, the Colorado River Compact of 1922, the competition for Colorado River water among states and users, and water rights, including legal challenges to rights and uses.

11. At the end of Part 6 students are asked to find information on the Internet on the status of snow and water resources both for their local areas and for the states they are representing as U.S. senators. Several URLs are given to help them in their searches.

12. To save time, you may choose to skip **Part 7: Is water rationing in your future?** and Question 7.
    - This portion of the investigation acquaints students with water rationing and personal water use. It challenges students to decide how they would use water when faced with strict rationing (Question 7).
    - If you include this, have students create their own categories for personal water use (as suggested in the **Briefing**). Alternatively, have them fill out the **Personal Water Use Survey** below.
    - Remind students that personal water use is only a small part of total water use. For example, of total water use in California, approximately 11 percent is now used in urban areas by residences, industries, governments, and commercial enterprises; 42 percent is used for agriculture; 45 percent of the runoff is used for the environment. About 2 percent of developed water supplies is used for other reasons, such as recreation and energy production. <http://wwwdwr.water.ca.gov/dir-CA_Water_Resource/CA_Wtr_Supply-Needs.html>

**Personal Water Use Survey**

| Investigation | Normal Use | Conservation Use | 25 Gallons/Day Limit |
|---|---|---|---|
| Flushing | 5-7 gallons | With displacement bottles in tank, 4 gallons | |
| Showering | 25 gallons water running | 4 gallons, wet down, soap up, wash down | |
| Bathing | 40 gallons, tub full | 10 gallons, minimum level | |
| Brushing teeth | 5 gallons, tap running | <1 gallon, wet brush, turn water off, rinse | |
| Washing hands or face | 2 gallons, tap running | 1 gallon, plug and fill basin | |
| Drinking | 1 gallon, run water to cool | 8 ounces, keep water cool in refrigerator | |
| Cleaning vegetables | 3 gallons, tap running | <1 gallon, fill pan with water to clean | |
| Dishwasher | 16 gallons, full cycle | 7 gallons, short cycle | |
| Dishes by hand | 30 gallons, tap running | 5 gallons, wash and rinse in dishpan or sink | |
| Washing clothes | 60 gallons, full cycle, top water level | 27 gallons, short cycle, minimal water level | 25 gallons |
| TOTALS | 117-148 gallons | 59 gallons | |

Source: National Resources Conservation Service (http://pelican.gmpo.gov/edresources/water_5.html)

## *Concluding the Investigation*

13. Part 8 concludes the investigation with the Hearings of the Senate Subcommittee.
    - Form cooperative learning groups of seven so that each group has a representative—a senator—from each of the seven states: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.
    - Using the table in question 8 of the Log, each group should propose the allocation of Colorado River water among different uses and among each of the seven southwestern states.

## Evaluation

- Collect and evaluate students' **Logs** using the Key.

### *Log*

1. Give three reasons why snow is important in the Southwest?
    - *Possible answers include: Snow meltwater is the major source of water in the Southwest. It provides water for hydroelectric power or electricity, irrigation of crops, residential or domestic uses, industries, businesses, and recreation.*

2. Complete the following table:

**Water Supplies for Selected Southwestern Cities**

| City | Types and Locations of Water Sources |
|---|---|
| Las Vegas, Nevada | Groundwater has been main source, but that is now inadequate so are beginning to rely on importing Colorado River water. |
| Los Angeles, California | Snowmelt from the Sierra Nevada Mountains and Colorado River originating in the Rocky Mountains |
| Phoenix, Arizona | Snowmelt from the Mogollon Rim via Salt River Project provides 2/3rds of supply; local groundwater supplies 3%, about 1/3rd comes via Central Arizona Project, which taps Colorado River water. |
| Salt Lake City, Utah | Snowmelt from the Wasatch Mountains |
| San Francisco, California | Snowmelt from the Sierra Nevada Mountains stored behind Hetch Hetchy dam |
| Tucson, Arizona | Groundwater has been “mined” and is no longer adequate, so are using more and more of Colorado River water brought in by Central Arizona Project. |

3. How do droughts in the Southwest affect people and the physical environment? What do you think would happen if the Southwest experienced a drought lasting several decades?
    - *In dry years (called droughts), there is less snowmelt. Reservoirs dry up. Water is sometimes rationed. There are also more fires.*
    - *The student should extrapolate with more of the first part, with a healthy opportunity for creativity, e.g., impact on virtually all aspects of economic life.*

4. Name the seven states through which Colorado River water flows?

    - *Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. Students should note that waters tributary to the Colorado should be included, e.g., the Green River flowing out of Wyoming is a tributary to the Colorado River.*

5. Who are the major water users of the Colorado River? Who do you think *will* win the most in the fight for its water? Who do you think *should* win the most in the fight for its water? Why?

    - *The major water users are California, Nevada, Arizona, and Colorado. As to who **will** win the snowmelt water, there's no clear answer, but students should discuss the issue. If political and economic power are the main criteria for winning, then California would likely be the biggest winner. As to who **should** win the snowmelt water, see if students can determine if there is a geographic bias in answers.*

6. Briefly summarize the current status of snowpack or other water resources in your home state *and* in the state that you represent as a U.S. senator, and give your sources of information.

    - *The answer will depend upon your location.*

    - *The students may simply repeat the web site listed in the student guide.*

    - *If you live in an area that does not have this information on the Internet, you can ask students where they might find information about water supplies in a nearby large river basin.*

7. Assume that you normally use the average amount of water used per person in the United States. And assume that a severe drought forces you to ration your personal water use to only 25 gallons per day. If that were all the water you had, how would you use it? List below your personal daily uses and amounts totalling 25 gallons.

    *Answers will vary, even if students use the **Personal Water Use Survey.***

8. Meeting as the Senate Subcommittee on Future Water Policy in the Southwestern United States, complete the table below and be prepared to defend your allocations.

    *Answers will vary.*

## Additional Resources

Site at JPL devoted to the study of snow, ice, and glaciers with radar.
http://www.jpl.nasa.gov/radar/sircxsar/snowice.html

NASA's Goddard Space Flight Center Laboratory for Hydrospheric Processes is responsible for programs that include theory and experiments on snow and ice. One of the goals of the remote sensing of snow is to describe the spatial and temporal variability of snow cover.
http://hydro4.gsfc.nasa.gov/research_areas/snow.html

This site represents some of the best work of visualization specialists and NASA scientists. One of the best visualizations about glaciers and climate change, related to glacier bay. This page also indicates how you can order the excellent NASA video: Glacier Bay, Alaska, from the Ground, Air and Space.
http://sdcd.gsfc.nasa.gov/GLACIER.BAY/glacierbay.story.html

On this web site you'll find text, visualizations, pictures, and links relating an exciting research project studying Antarctica. The images and QuickTime movies are very well done.
http://svs.gsfc.nasa.gov/imagewall/antarctica.html

This site has links to NASA's MODIS Snow and Ice Global Mapping Project, as well as links to NASA Climate News, NSF's National Science and Technology Week: Polar Connections, The National Snow and Ice Data Center, Ice and Snow site, Scott Polar Research Institute, Ice Core Dating, Glaciers, Snow, Ice and Permafrost Research Projects, Nansen Environmental and Remote Sensing Center (NERSC), Snowtastic Snow, Cyberspace Avalance Center, and Antarctic Warming—Early Signs of Global Climate Change
http://snowmelt.gsfc.nasa.gov/MODIS_Snow/snowice.web.addr.html

This site, supported by NASA, is a gold mine of information on general snow information links, avalanche awareness, glaciers, snow removal efforts in the United States, the blizzards of 1996, ice shelves and icebergs, and an introduction to the method NSIDC uses to store satellite sensing data in "grids"
http://www-nsidc.colorado.edu/NSIDC/EDUCATION/

Information on the geography of the wildfires in the West
http://wildfire.usgs.gov/html/geomacpublichome.html

Search the status of the water supplies in your area
http://www.wcc.nrcs.usda.gov/water/quantity/westwide.html

Water supply outlook for the western United States, including mountain snowpack maps and reservoir storage graphics. State basin reports for the current water year.
http://www.wcc.nrcs.usda.gov/water/quantity/st_report.html

Adolescent-oriented news about life and ice and snow
http://www.southpole.com/

Good information on water and water conservation
http://pelican.gmpo.gov/edresources/water_5.html

The National Drought Mitigation Center helps people and institutions develop and implement measures to reduce societal vulnerability to drought. The NDMC stresses preparation and risk management rather than crisis management. You can review the drought histories of different states. You can create graphs of the historic droughts experienced by different states, for example, California.
http://enso.unl.edu/ndmc/
http://enso.unl.edu/ndmc/climate/palmer/calif.gif

If you live in California or southern California, these sites will be interesting:
http://rubicon.water.ca.gov/b160index.html (California Department of Water Resources, Bulletin 160-98: California Water Plan, 1998 update. This has lots of information for students living in California.)
http://www.mwd.dst.ca.us/index.htm (The metropolitan water district of southern California site. This would be of use for educators in southern California.)

Reisner, Marc. *Cadillac Desert.*
http://www.pgs.org/kteh/cadillacdesert/home.html

Postel, Sandra. *Last Oasis.* Norton/Worldwatch Books. 1998.

Conniff, R. November 1993. California: Desert in disguise in water. The power, promise and turmoil of North America's fresh water. November 1993. *National Geographic* Special Edition, p. 38-53.

Jim Carrier, June 1991, The Colorado. A river drained dry. *National Geographic*, v. 179 (6) 4-35.

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

### Background

There is little chance that you would experience snowfall in one of the big cities of the southwestern United States. Los Angeles, San Francisco, Las Vegas, and Phoenix are too low in elevation to get snow; it is just not cold enough. And yet these cities depend upon snow for their water supplies. Mountains get the snow, the snowmelt is stored in reservoirs, and the water is then moved in streams and aqueducts to supply farms, cities, and industries, which in some cases are hundreds of miles away from the mountain snows (Figure 1).

This may seem like an ideal situation, except for two potential problems of water supply and water demand: drought and population growth. In the generally arid Southwest, a prolonged drought can mean that there is too little snowfall in the mountains to resupply the reservoirs. The other potential problem is that the Southwest has the fastest growing population of any region in the United States, and this population is making unprecedented demands on the water supply. Underlying these potential regional problems is the fact that *each* of the southwestern states seeks to increase its *own* water supply.

**Figure 1: Snow and snowmelt in the mountains of the western United States**

Source of top image: http://snowmelt.gsfc.nasa.gov/MODIS_Snow/snow.html
Source of bottom image: ftp://ftp.wcc.nrcs.usda.gov/images/snomlt01.jpg

### Objectives

In this investigation, you will

- use satellite imagery and other sources to find and organize information about the water supplies of major cities in the southwestern United States,
- consider the ways in which droughts in the Southwest affect people and the physical environment,
- learn about water management policy and water law in the Southwest,
- find out how ground crews and remote sensing measure mountain snowpacks to aid the planning of water managers,
- use Internet sites to find the status of snowpack or other water resources in one or more states,
- project personal water use under severe water rationing, and
- apply your knowledge to role-play a member of a U.S. senate subcommittee making recommendations on water policy issues in the Southwest.

### Scenario

You are to play the role of a U.S. senator from one of the following states: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. You are to represent your state on the Senate Subcommittee on Future Water Policy in the Southwest. Specifically, the subcommittee is charged with proposing the allocation of Colorado River water (1) among different uses and (2) among the southwestern states. This investigation will help you prepare for your role as a member of this subcommittee, which will meet to do its business near the end of this investigation.

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

### Part 1. Why is this investigation important?

Springtime melting of mountain snows helped ancient civilizations flourish. For example, Mesopotamia depended on water from snowmelt in the Tigris and Euphrates Rivers to irrigate crops, and Hohokam peoples from the Phoenix Valley, Arizona, dug many canals to move the snowmelt water from the Salt River to their crops. And new canals along similar routes now supply snowmelt to millions of inhabitants of the Phoenix area.

Today, snowmelt is stored in reservoirs behind dams so it can provide water and energy. For example, Lake Powell stores the water behind Glen Canyon Dam (Figure 2). The water released by dams drives turbines that generate hydroelectric power. The hydroelectric power from Glen Canyon Dam supplies cities in the Southwest such as Las Vegas, Phoenix, and Los Angeles.

When the Colorado River reaches the Gulf of California, the once-mighty river is a mere trickle after upstream users have dammed it and siphoned off its water (Carrier 1991). Little is left of the Colorado below the Glen Canyon Dam in Arizona to sustain natural ecosystems and their aquatic life, a fate that other rivers around the world share. Each year, the supply of clean fresh water becomes more scarce, as more and more people are living in dry, “water-stressed” areas, according to research reported by Dr. Kenneth Strzepek at the American Geophysical Union meeting in San Francisco in 1999 (Denver Post 1999). Computer models show that one-third of the world’s people live in areas classified as “water-stressed,” meaning the demand for clean fresh water exceeds the supply. In addition to the Colorado River basin, other water-stressed areas include the regions near China’s Yellow River, Africa’s Zambeze River, and the Syr Darya and Amu Darya Rivers that flow into the Aral Sea in central Asia.

### Part 2. What is NASA’s role in this issue?

NASA uses satellites to monitor the amount of snow and ice on Earth (Figure 3). Instruments aboard satellites sense a type of microwave radiation that is emitted and scattered by snow. Different snow conditions are associated with different microwave signals, which are received by satellite instruments.

**Figure 2: Ground and space views of the Colorado River and Lake Powell, Arizona and Utah, taken along the river and also by astronauts aboard Space Shuttle *Columbia*.**

The water of the Colorado River starts as snowmelt in the Rocky Mountains to the east (right of picture). The water then moves through the dry Southwest, as shown in this photograph, but dams help store the water. The blue color to the left of the Space Shuttle’s tail is the valley of the Colorado River flooded by snowmelt.

Source of Space Shuttle imagery:
http://images.jsc.nasa.gov/images/pao/STS-73/73727045.JPG

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

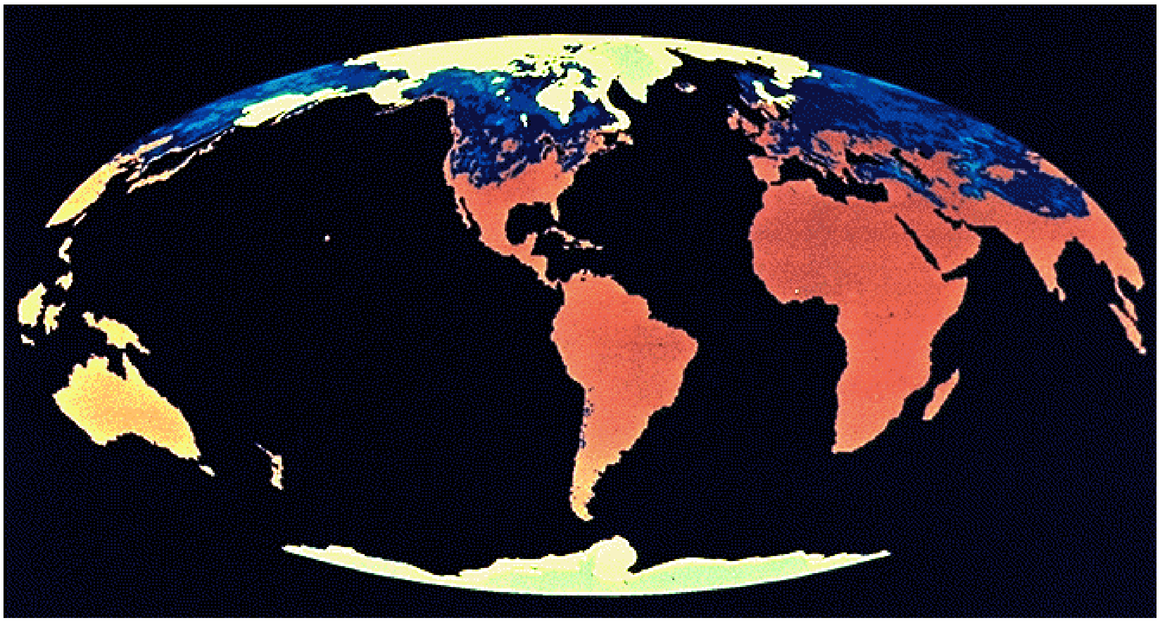

**Figure 3: This image comes from NASA's Nimbus-7 satellite. It shows global snow and ice coverage in the Northern Hemisphere winter. In this image, blues from light to dark indicate snow depths ranging from deep to thin. Sea ice is white. Areas not covered by snow are red to brown.**

Source: http://eospso.gsfc.nasa.gov/eos_edu.pack/p26.html

NASA monitors and maps snow cover for many reasons. Snow cover is important in developing military strategies and even national foreign policy. Snow cover affects the climate of continents and Earth as a whole. Thus, by gaining more accurate information about properties and effects of snow cover, scientists hope to develop a better understanding of Earth's climate. And the monitoring of mountain snowpack is crucial to the economic life of peoples in many parts of the world, including, as you will see, the southwestern United States.

Throughout this investigation you will find a number of <u>underlined questions</u>. Write your answers to these questions on the Investigation Log at the end of the Briefing. Your answers will prepare you to play your role as a member of the Senate Subcommittee on Future Water Policy in the Southwest.

<u>Answer Question 1 in the Log.</u>

### Part 3. How much do cities in the Southwest depend on snow?

Part 3 gives information about the water supplies of selected cities in the Southwest. As you work through Part 3, <u>organize this information by completing the table at Question 2 in the Log.</u>

Look at the mountains and rivers of the Southwest (Figure 4 or an atlas). Each river system catches water over an area called a *watershed*. In a watershed, the tributaries (smaller streams) feed all their water to the main stream. Then, the river system uses gravity to move the water to the ocean or a lake. More than 75 percent of the water in the large river systems on Figure 4 start in mountains as snowfall. It typically takes 25.4 centimeters of snow to melt down to 2.54 centimeters of water.

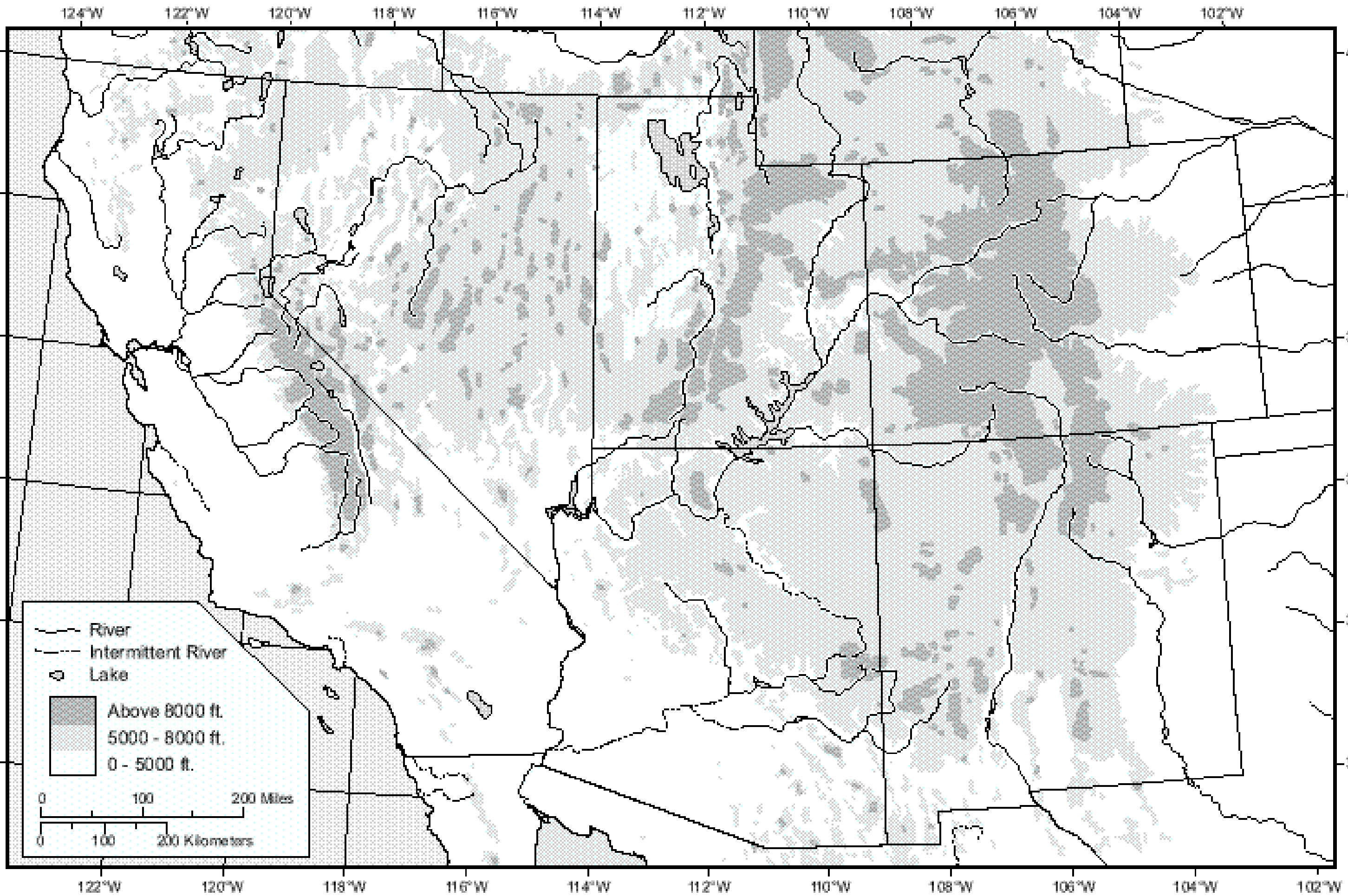


**Figure 4: Map of the topography and rivers in the southwestern United States**

Courtesy: Arizona Geographic Alliance
Department of Geography, Arizona State University
Douglas Minnis

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

Locate **San Francisco** on Figure 4 using an atlas. Now look to the east of San Francisco at the high land (dark shading) called the Sierra Nevada Mountains. At the start of the 1900s, the city of San Francisco had a population and industry that needed more water than local watersheds could provide. So San Francisco built a dam in Hetch Hetchy Valley in the Sierra Nevada Mountains to trap snowmelt for its citizens and industry.

Now examine a NASA satellite view of San Francisco (Figure 5). Most of NASA's imagery is from directly overhead or in **planimetric view**. Figure 5 presents a different type of view—a view from the side, or **oblique view**.

Now locate **Phoenix** on Figure 4 using an atlas. Also, on Figure 4, look north and east of Phoenix at the high land (dark shading)—called the Mogollon

**Figure 5: NASA's SeaWiFS satellite view of the San Francisco Bay area, California's Central Valley, and the snow-capped Sierra Nevada mountains**

The brown around San Francisco Bay is the color of the cities. The green shows vegetation with dark green being trees. The two large lakes in the middle of the white snow are Lake Tahoe (upper left) and Mono Lake (upper right). The snowmelt flows to the west (to the bottom of the image) and makes its way through the Sacramento and San Joaquin Rivers. Diversion structures route some of the snowmelt water to San Francisco, some through aqueducts to thirsty southern California, and some flows naturally through the rivers and delta. This natural flow is to preserve endangered fish: winter-run Chinook salmon; the tiny Delta smelt; and the Delta splittail.

Source: http://svs.gsfc.nasa.gov/imagewall/SeaWiFS/zoom_sanfran.html

**Figure 6: Snow at the Grand Canyon, Arizona, as seen from the Space Shuttle on February 9, 1994**

Although Arizona is mostly desert, this shows that snow covers Arizona's high country. The zone of dark color running parallel to the snow line is the pine forest. Pine forest and snow cover the Mogollon Rim of Arizona in most winters.

Source: http://images.jsc.nasa.gov/ images/pao/STS60/20120924.jpg

# Module 1, Investigation 4: Briefing
## Why is snow important in the southwest United States?

Rim. The Mogollon Rim is high country (not really mountains) with pine trees and winter snow (Figure 6).

At the start of the 1900s, Phoenix was only a small city. But Phoenix was located near rivers with very large watersheds up in the Mogollon Rim. Most of the people living in the Phoenix area were farmers, and they started the Salt River Project to manage these watersheds for irrigation.

Phoenix lies in a desert with an average of only 18 centimeters of rainfall a year. But unlike San Francisco, Phoenix does not have to bring water from a great distance. It comes directly to them from its watersheds to the north and east.

Throughout the first half of the 20th century, the Salt River Project built dams to hold water coming down the Verde River from the north and Salt River from the east (Figure 7). About two-thirds of the Phoenix area's water supply comes from the Salt River Project. Most of the water in these reservoirs comes from snowmelt, which is stored behind dams (such as Roosevelt Dam) and distributed by canals to farms, cities, and industries. Local groundwater contributes about 3 percent of the Phoenix supply, and almost one-third of the supply comes from the Central Arizona Project, which taps the Colorado River at Lake Havasu some 536 kilometers away.

Locate **Salt Lake City** and the Great Salt Lake on Figure 4 using an atlas. Find the highlands to the

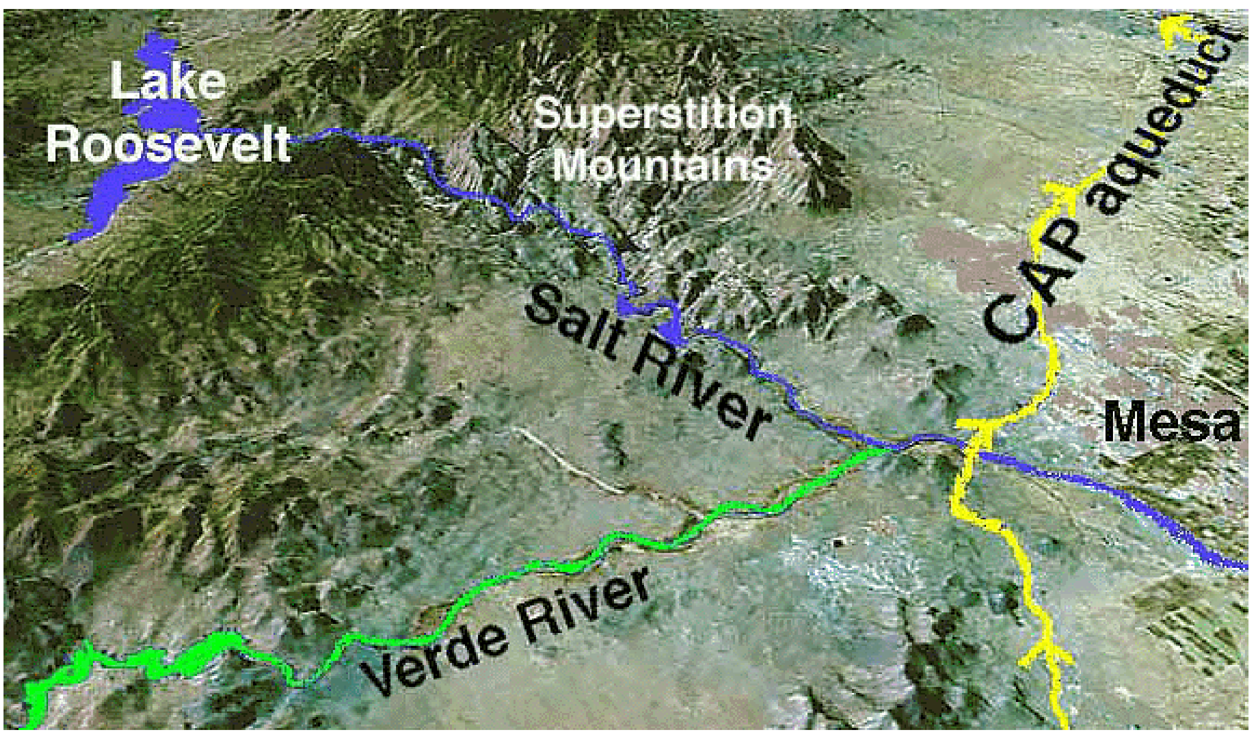


**Figure 7: Satellite view of the water sources feeding the Phoenix metropolitan area, where the water is managed by the Salt River Project. The view is looking to the southeast. Mesa is on the eastern side of the Phoenix area. The CAP is the Central Arizona Project.**

Source: LANDSAT 1993 Thematic Mapper image combined with digital elevation data available from the U.S. Geological Survey. The 1993 year was very wet, fostering a lot of vegetation growth (green color in this image) in the normally dry desert.

# Module 1, Investigation 4: Briefing
## Why is snow important in the southwest United States?

**Figure 8: Salt Lake City depends on snow from the Wasatch Range, seen as white on this Space Shuttle photograph**

The importance of snowmelt can even be seen in the color of the Great Salt Lake, Utah. The lake appears as two separate bodies of water with a narrow divider in the middle. At the turn of the century, a railroad bridge without culverts was built across the lake, and ever since, the water and salinity levels have been unequal. The lower right side gets more snowmelt and has more freshwater. When there is too much snowmelt from the nearby Wasatch Mountains, the lake can flood local lowlands.

Source: http://images.jsc.nasa.gov/images/pao/STS36/10063852.htm

east (the dark shading on Figure 4) called the Wasatch Mountains. Salt Lake City lies at the foot of the Wasatch Mountains. The snow from the Wasatch provides water for the cities, agriculture, and industry of the Salt Lake City area. The importance of snowmelt is also seen visually from outer space in Figure 8.

Locate **Los Angeles** on Figure 4 using an atlas. Los Angeles does have some mountains nearby, but the metropolitan area is so large that there isn't enough snow in these mountains to meet the needs of the region.

As early as 1913, the Los Angeles Department of Water started to bring water to the city from great distances. Cities in the Los Angeles metropolitan area now get water from the snow of two mountain areas far away. One major source of water is the Sierra Nevada Mountains (Figure 9). The other major source of water comes from the Rocky Mountains through the Colorado River and the

Colorado River Aqueduct (Figure 2). Some southwestern cities rely mainly on local groundwater rather than snowmelt. Las Vegas, Nevada, and Tucson, Arizona, (locate them on Figure 4) are two large cities that have been pumping much of their water from wells. But both of these cities faced major water crises at the start of the 21st century. Both cities have been "mining" their groundwater. This means that they have been taking water from wells faster than rainfall can resupply the groundwater. They have mined groundwater because populations have grown too fast and too large for the water supply.

So what are Las Vegas and Tucson doing? They are importing water from somewhere else. Both of these cities are trying to get more and more water from the Colorado River, which has its origin in the snow of the Rocky Mountains (Figure 2).

An aqueduct called the Central Arizona Project (CAP) brings water hundreds of miles from the Colorado River to Tucson (Figures 7 and 10). And although the CAP water tastes worse than groundwater and rots pipes of older homes, Tucson has no choice. There just isn't enough local groundwater to support Tucson's growing population.

Contaminated ground water is an increasing threat to human health in some regions. If alternative sources of water are available, such as from snow, these regions are fortunate. For example, in December 1999, Fort Morgan, a small city northeast of Denver on Colorado's Eastern Plains, joined many other northern Colorado cities that get municipal water from snow in the Colorado River Basin (Coleman 2000). The water, which originates in and around Rocky Mountain National Park northwest of Denver, is delivered to the Front Range region east of the Rockies by the Colorado River-Big Thompson River Project. This system of reservoirs, pipelines, pumping stations, and canals takes water from the Colorado River on the western side of the Rockies and moves it to the Big Thompson watershed on the eastern side. Fort Morgan's switch to mountain snowmelt meant that its population no longer had to use groundwater

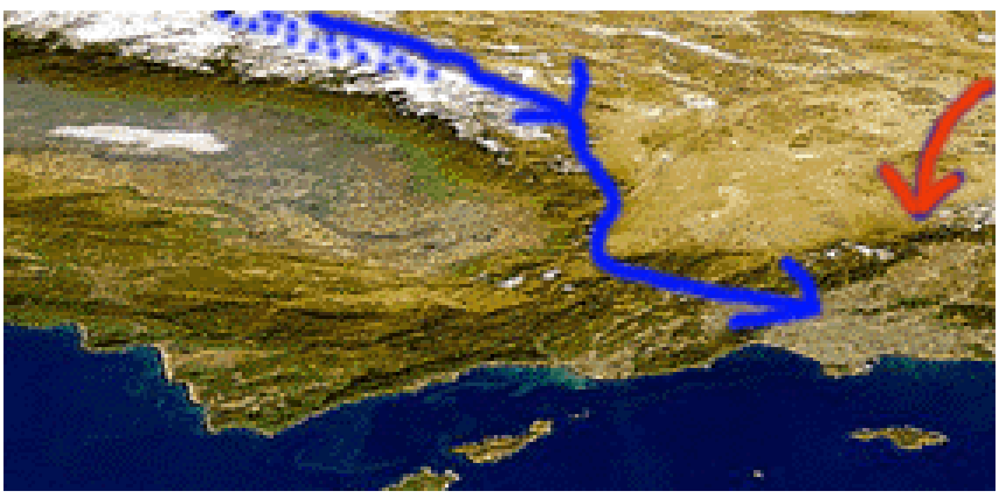

**Figure 9: The Los Angeles metropolitan area is in the lower right corner of this SeaWiFS image from NASA**

The blue dots represent the watershed of the eastern Sierra Nevada Mountains whose water rights were purchased by the Los Angeles Department of Water (LADWP). LADWP built two aqueducts—one in 1913 and the other in 1970—to bring water to the city of Los Angeles. The blue and red lines show the pathway of water that comes from the Sierra Nevada (blue) and Colorado River (red).

Source: http://svs.gsfc.nasa.gov/imagewall/SeaWiFS/zoom_losangeles.html

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

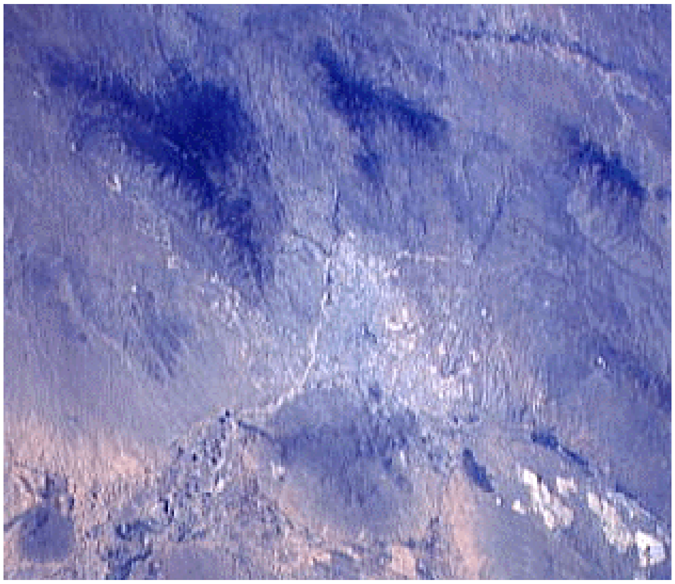

**Figure 10: The desert city of Tucson, Arizona, as seen by the Space Shuttle in 1994**

The light-colored area in the middle of the photograph is Tucson. The dark areas to the east (up) are mountains that surround Tucson. Most of the lowlands in the image look light brown because vegetation is scarce in this arid area.

Source: http://images.jsc.nasa.gov/iams/images/earth/STS039/lowres/10020684.jpg

that had become increasingly polluted by nitrates from agricultural fertilizers.

The Fort Morgan example raises another issue. There is rapid urban growth in Colorado's Front Range communities (Long 1996). The Denver metro area is the center of this rapidly urbanizing region stretching from Fort Collins in the north to Pueblo in the south. This area is another major competitor for Colorado River water.

### Part 4. How dependable are the snows?

Are you getting the impression that millions of people in the southwestern United States depend on snowmelt? You are absolutely right! And if you are thinking that snowfall might not be dependable, you are right again. Some winters have almost no snow in the mountains. The climate record in the Southwest shows great variability—big swings in precipitation from year to year. Generally, the drier the climate, the greater the variability. So, in the Southwest, the driest quarter of the United States, you can expect the greatest variability.

The table below illustrates this variability.

1987-1992 Drought

- In California, reservoirs holding water declined; some dried up.
- Water was rationed in California.
- People in cities began conserving water.
- New California laws tied real estate development to water supplies.

1993-1998 Snowy Years

- Water surplus

1999-2000 Drought

- Ski resorts in California and Colorado experienced poor skiing conditions and loss of business.
- In December 1999, the snowpack in the Central Rockies was only half of normal.
- The winter of 1999-2000 was the driest in Arizona since records were kept.
- In summer 2000, Roosevelt Reservoir, which supplies Phoenix, was only 17% of normal and was projected to go down to 10%.

Unfortunately, the drought of 1987-1993 was not the greatest one on record. The Southwest experienced much longer droughts around 1000 A.D. and 1300 A.D. There is evidence of a very long drought centered around 1300 A.D. that lasted about 160 years. It was so dry that the high alpine lakes of the Sierra Nevada Mountains stopped overflowing. Even in the worst *recent* droughts, these same lakes have *always* overflowed.

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

Droughts do more than ruin a ski season, make reservoir levels drop, and force water rationing. Plants on hillsides dry out and burn easily in wildfires. Major fires occur during droughts. In the United States, over 5 million acres were burned in the summer of 2000, which had the largest number of wildfires in many decades. NASA has a team of fire specialists that study fires with remote sensing while the fires are burning. For example, see <http://asapdata.arc.nasa.gov/YellowstoneFire.jpg>.

Answer Question 3 in the Log.

### Part 5. Who's in charge of the water?

If you are thinking that the answer depends on the place, you are a natural geographer. Geographers tend to answer questions like this at different scales. This means that if you kept zooming in from outer space you would get different answers. If you zoomed way up close and looked at a city, the usual answer is that the city is in charge of the water. If you zoomed out, there are often planning regions for different parts of a state. For example, the Salt River Project distributes water to many cities in the Phoenix area. If you zoomed out even more, states have some control of water. But for the Southwest as a whole, there is an out-and-out fight for control of the major water source—the Colorado River (Carrier 1991).

Sometimes called the "jugular vein" of the Southwest, Colorado River water flows through seven states, and eventually into Mexico (Figures 2 and 11). About 85 percent of Colorado River water is used by agriculture.

Answer Question 4 in the Log.

The amount of Colorado River water each state gets was first determined by the Colorado River Compact of 1922. This agreement divided these seven states into upper and lower basins (Figure 11) and allocated 7.5 million **acre-feet** (maf) per year to each basin. At the time, the total flow was thought to be 17 maf per year (For comparison, the average annual flows of the Mississippi and Columbia rivers are 400 and 192 maf, respectively.) But since 1930, the Colorado's flow has averaged only 14 maf. A 1944 treaty guaranteed Mexico 1.5 maf. Today, evaporation from reservoirs removes about 2 maf.

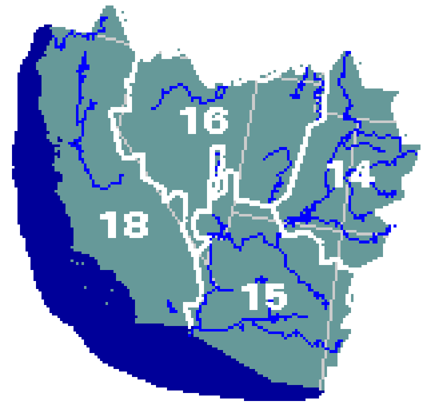


**Figure 11: Water resources regions of the southwestern United States, as defined and used by the U.S. Geological Survey.**

14 is the Upper Colorado River Basin.
15 is the Lower Colorado River Basin.
16 is the Great Basin.
18 is California.

Source: http://water.usgs.gov/images/regions.gif

Of the seven states, three take most of the water—California, Nevada, and Arizona. Mexico only gets water in wet years when there is a surplus. According to the Compact of 1922, California is

> **How much is an acre-foot?**
> An acre-foot is the amount of water spread over an acre a foot deep. An acre-foot is 325,850 gallons.
>
> **How can you visualize a million gallons?**
> The usual bathtub holds 40 gallons, so a million gallons would be 25,000 baths. A pool that would hold a million gallons would be as long as a football field, 10 feet deep, and 50 feet across.

permitted to use 4.4 maf each year, but for most years, California has used far more than its allotment. Now, Arizona and Nevada are demanding some of the water that California has been taking. At the start of the 21st century, U.S. Secretary of the Interior Bruce Babbitt tried to force California to reduce its use to the agreed-upon amount, but in the year 2000, California was still taking more than its allotment.

Finally, California agreed to meet with Arizona and Nevada to sort things out. Arizona and Nevada hoped to force California to keep to its agreement. Californians wanted the Colorado River's water distributed according to population (of course, California has the largest population by far). At the turn of the 21st century, Nevada and Arizona ranked #1 and #2 among the states in the rate of population growth. And in Colorado, the state that is the source of the Colorado River, the rate of population growth is also among the highest in the nation. Also, Mexican agriculture (which produces a large share of its products for the U.S. market) has water needs as well.

Nobody knows for sure whether the states will keep to the old agreement, whether there will be a new agreement, what a new agreement will look like, or what will happen to the Colorado River water.

Answer Question 5 in the Log.

Another way to answer the question **Who's in charge of the water?** is to understand which user legally owns the right to water. The primary law controlling water rights in the West is "first in time, first in right." In other words, water is the property of those who used it first, which is called "prior appropriation." This law usually applies at the level of the individual water user.

The major users of water are agriculture, towns and cities, industries, and the physical environment (ecosystems require water to sustain them).

But legal rights to water can be challenged. For example, environmentalists won a major fight in court against the City of Los Angeles, which was importing water from the sources that feed Mono Lake. Five decades of this caused the surface of Mono Lake to drop 40 feet, which threatened that unique ecosystem. Environmentalists won a 15-year court battle, and Los Angeles was forced to reduce flow diversions to allow Mono Lake to rise to healthy levels.

It is even possible for Native American farmers to win water battles in court. Take the example of the Akimel O'odham (Pima Indians), who resided along the Gila River for centuries (Figure 4 at about 32˚N, 111˚W). In 1859, the Gila River Reservation was established, the first in Arizona. Anglo-American farmers settling in areas up river from the Akimel

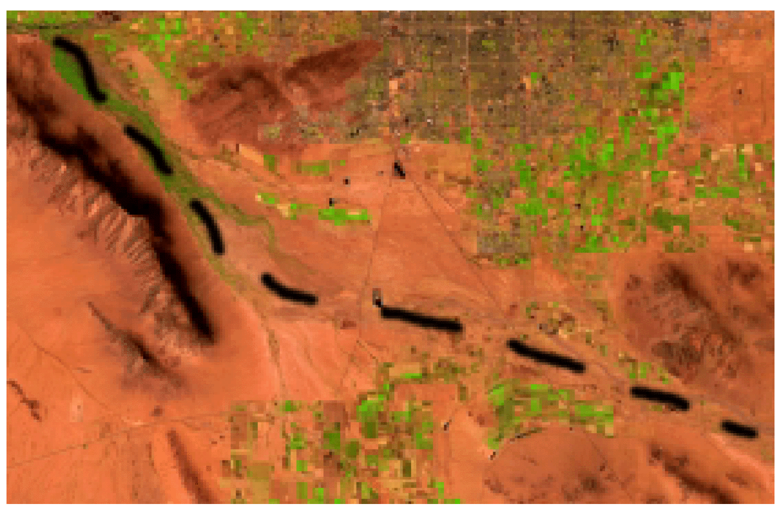

**Figure 12: Before Coolidge Dam, the Gila River flowed all year round. Now, this NASA LANDSAT image shows the Gila to be dry (position shown by black dashed line).**

Now that the Akimel O'odham will be getting water returned to the Gila, NASA imagery can be used to monitor changes. The green shows vegetation in irrigated farms, and the growing south edge of the Phoenix metropolitan area is at the top of the image.

Source: http://svs.gsfc.nasa.gov/imagewall/LandSat/

# Module 1, Investigation 4: Briefing
## Why is snow important in the southwest United States?

O'odham built water-diversion structures and then Coolidge Dam (Schroeder 1973). Figure 12 shows the effects of this diversion of snowmelt: a dry river most of the year in place of a formerly year-round (perennial) flowing stream—a dry condition that is once again set to change. The Akimel O'odham recently won a battle in court to have some of the Gila River's water returned. Future NASA imagery can be used to document the changes to the Akimel O'odham and their lands.

### Part 6. How can you tell if there is enough snow?

Water managers need to know how much water is in the snow. They do this in different ways. Snow surveyors go into the mountains and measure the depth and water content of the snow (Figure 13). There are also automated stations to measure snow. But under the current system, people must visit sites, and there are hazards to travel in the backcountry (Figure 14). Thus, NASA scientists are also exploring ways to measure the amount of water in the snow with satellite sensors.

Snow hydrologists are using Spaceborne Imaging Radar-C and X-Synthetic Aperture Radar (SIR-C/X-SAR) data to determine water held in seasonal snowpacks. SIR-C/X-SAR is a powerful tool because it can measure most snow pack conditions (Figure 15).

Using satellites to measure snow is not yet as reliable as field measurements. But because field


**Figure 13: Snow surveyor weighing snow to determine water content**

Source: ftp://ftp.wcc.nrcs.usda.gov/images/survey02.jpg


**Figure 14: Helicopter crashing—the downside of doing snow surveys in person, and a good reason to investigate safe remote-sensing alternatives**

Source: ftp://ftp.wcc.nrcs.usda.gov/images/helicrsh.jpg

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

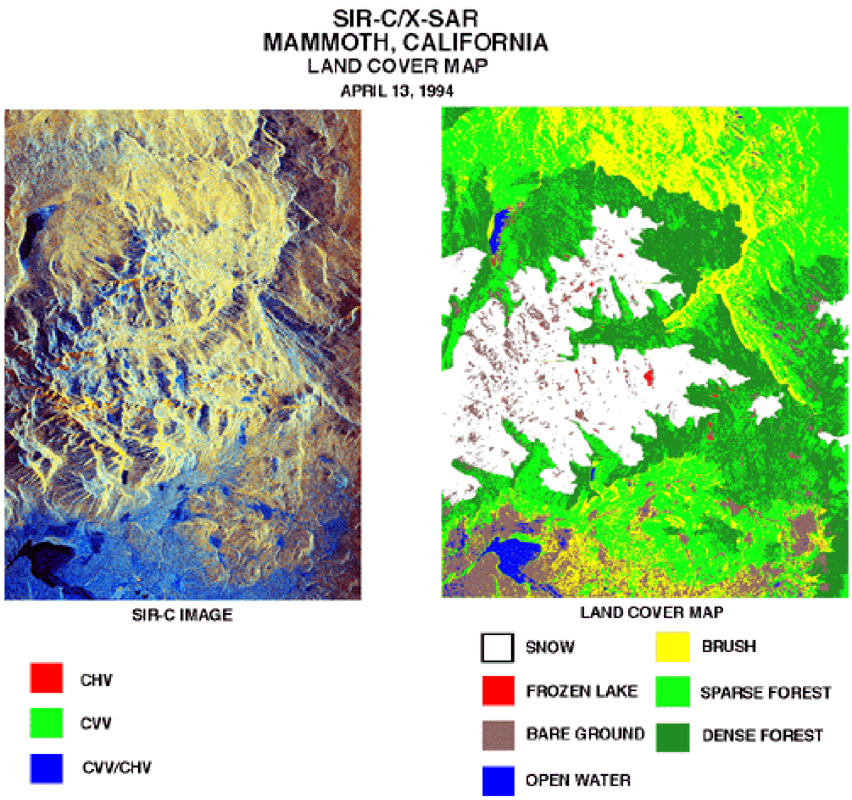


**Figure 15: Radar is being used to study snow. The image on the left and the map on the right are of the Mammoth Mountain area in the Sierra Nevada Mountains, California.**

The image is centered at 37.6˚ N 119.0˚ W. The 11.5 kilometers by 78.3 kilometers area is a part of the watershed of the city of Los Angeles. On the radar image, blue areas are lakes or slopes facing away from the radar illumination. Yellow represents areas of dry, old snow as well as slopes facing directly the radar illumination. The radar image on the left was acquired by the SIR-C/X-SAR aboard Space Shuttle *Endeavour* on its 40th orbit, April 11, 1994. The time of the overflight was towards the end of the snow season. Total snow depth was about 1 to 1.5 meters, only about 40 percent of the average.

Source: http://www.jpl.nasa.gov/radar/sircxsar/mammoth-land.html

work is dangerous and time consuming, the hope is that satellites will someday provide an accurate picture of water resources in snow—and not just in the United States.

Many developing countries depend on snowmelt for water and hydroelectric power; remote sensing of the snowpack would be a great help to planning. Water managers put their information on Internet sites. Thus, you can also learn if your local area is having a wet year or a dry year. Keep in mind that Internet sites change. Here are sites where you can find the depth of your snowpack or the amount of water in the reservoirs that water your city or town.

Water supply outlook for the western United States, including mountain snowpack maps and reservoir storage graphics
http://www.wcc.nrcs.usda.gov/water/quantity/westwide.html

State basin reports for the current water year
http://www.wcc.nrcs.usda.gov/water/quantity/st_report.html

For example, somebody living in Phoenix, Arizona, can find water storage along the Salt River at <http://www.wcc.nrcs.usda.gov/water/quantity/st_report.html>. In April 1999, a person in the Phoenix metropolitan area would have learned at that site that storage was below average conditions (Figure 16)—even before the major drought of the winter of 1999-2000.

You can also obtain an outlook for the water supply throughout the western United States at <http://uinta.cbrfc.noaa.gov/product/westwide/>.

Another important source to check out is the Colorado Basin River Forecast Center: <http://www.cbrfc.gov/> where you can obtain forecasts throughout this large watershed.

<u>Answer Question 6 in the Log.</u>

# Module 1, Investigation 4: Briefing

## Why is snow important in the southwest United States?

### Part 7. Is water rationing in your future?

The average person in the United States uses 168 gallons of water a day. In future droughts, the chances are good that water will be rationed. Consider conditions in the state of California. By the year 2020, California's population is estimated to reach 48 million (http://rubicon.water.ca.gov/b16098/estxt/esch4.html) with 41 million living in cities (http://www.ruralhealth.cahwnet.gov/demographics/graphs.htm). If California experiences the type of drought that it did in 1987-1993 (when it received only three-fourths of its average amount of water), people living in cities might be forced to cut back to as little as 25 gallons per day per person. This is an extreme scenario, but it could happen under conditions of extreme drought. One thing is sure: The first indications of the need for rationing in the future will come from satellite monitoring devices. The quicker we are able to remotely sense the need for action, the better we can plan.

Answer Question 7 in the Log.

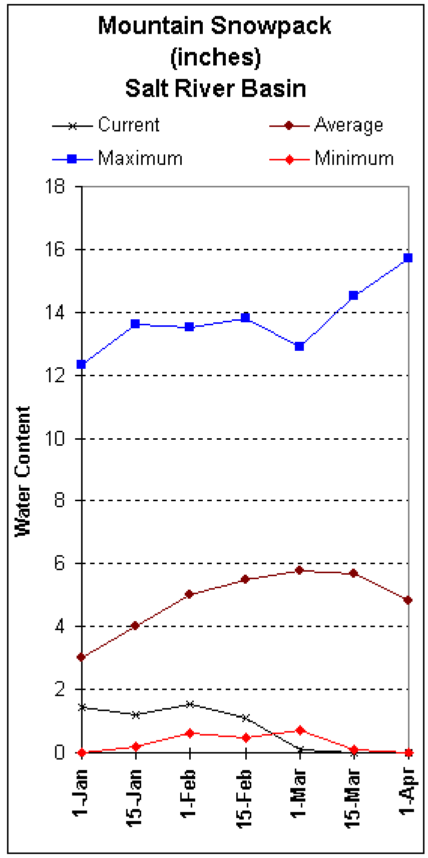


**Figure 16: Salt River, Arizona, water levels as of April 1, 1999**

Source: http://www.az.nrcs.usda.gov/snowsurv/wy99/apr1/az4s20.htm

### Part 8. Hearings of the Senate Subcommittee on Future Water Policy in the Southwestern United States

The seven members of the subcommittee should propose principles to guide allocation of water (1) among different uses and (2) among the southwestern states. They should also vote to determine proposed allocation of Colorado River water. Your subcommittee's allocation proposal should be recorded on the table in the Log at Question 8.

## References


Brazil, Eric. 2000. Snowpack in Sierras 22 percent of normal. *Denver Post*. January 13.

Carrier, Jim. 1991. The Colorado: A river drained dry. *National Geographic* June: 2-35.

Cornelius, Coleman. 2000. Tapping the Rockies: Fort Morgan is latest city to pipe in mountain water. *Denver Post*, January 3.

*Denver Post.* 1999. World's clean water supply shrinking. December 17: 4B.

Long, Michael E. 1996. Colorado's Front Range. *National Geographic* November: 80-103.

Schroeder, Albert H., editor. 1973. *The changing ways of southwestern Indians* . Glorieta, New Mexico: Rio Grande Press, Inc.

# Module 1, Investigation 4: Log

## Why is snow important in the southwest United States?

1. Give three reasons why snowmelt is important in the Southwest?

2. Complete the following table:

**Water Supplies for Selected Southwestern Cities**

| City | Types and Locations of Water Sources |
|---|---|
| Las Vegas, Nevada | |
| Los Angeles, California | |
| Phoenix, Arizona | Snowmelt from the Mogollon Rim via Salt River Project provides 2/3 of supply; local groundwater supplies 3%; about 1/3 comes via Central Arizona Project, which taps Colorado River water. |
| Salt Lake City, Utah | Snowmelt from the Wasatch Mountains |
| San Francisco, California | |
| Tucson, Arizona | |

3. How do droughts in the Southwest affect people and the physical environment? What do you think would happen if the Southwest experienced a drought lasting several decades?

# Module 1, Investigation 4: Log

## Why is snow important in the southwest United States?

4. Name the seven states through which Colorado River water flows.

5. Who are the major users of the Colorado River? Which states do you think *will* win the most in the fight for its water? Why? Which states do you think *should* win the most? Why?

6. Briefly summarize the current status of snowpack or other water resources in your home state *and* in the state that you represent as a U.S. senator and give your sources of information. You should use this information as a member of the Senate Subcommittee on Future Water Policy in the Southwestern United States.

7. Assume that you normally use the average amount of water used per person in the United States. And assume that a severe drought forces you to ration your personal water use to only 25 gallons per day. If that were all the water you had, how would you use it? List below your personal daily uses and amounts totalling 25 gallons.

# Module 1, Investigation 4: Log
## Why is snow important in the southwest United States?

8. Meeting as the Senate Subcommittee on Future Water Policy in the Southwestern United States, complete the table below and be prepared to defend your allocations.

**Proposed Allocation of Colorado River Water, by States and Uses, in Million Acre-Feet (maf)**

| State | Urban | | Agriculture | | Environment | | Other | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|
| | maf | % | maf | % | maf | % | maf | % | maf | % |
| Arizona | | | | | | | | | | 100 |
| California | .05 | 11 | 1.9 | 42 | 2.0 | 45 | 0.1 | 2 | 4.5 | 100 |
| Colorado | | | | | | | | | | 100 |
| Nevada | | | | | | | | | | 100 |
| New Mexico | | | | | | | | | | 100 |
| Utah | | | | | | | | | | 100 |
| Wyoming | | | | | | | | | | 100 |
| Mexico | | | | | | | | | | 100 |
| TOTAL | | — | | — | | — | | — | 10.0 | 100 |

### Notes
- Urban uses include residences, industries, governments, and businesses.
- Environment is the runoff needed to maintain ecological systems.
- Other uses include recreation and energy production.
- Currently, 85 percent of all Colorado River water use is for agriculture.
- The total amount of water to be allocated in the table is 10.0 maf.
- Percentages total to 100 across, but not down.
- Amounts for California approximate current use and are shown as an example. If you wish to propose different allocations for California, write them in the same boxes below the current figures.
- Currently, Mexico receives no Colorado River water.